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Agroforestry as a sustainable land use option to reduce wildfires risk in European Mediterranean areas

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Abstract

Abstract Wildfires have always been an integral part of the ecology of many terrestrial ecosystems, but their frequency is increasing in many parts of the world. Wildfires were once a natural phenomenon, but after humans learned to control fire, it has been used as a management tool to increase soil fertility, to regenerate natural vegetation for grazing and to control competing vegetation. However, currently uncontrolled wildfires threaten not only natural vegetation, landscape biodiversity, communities and economies, but they also release large amounts of carbon dioxide, thus contributing to global temperature increase. Higher temperatures and drier summers have increased the risk of wildfires in biodiversity rich areas of European Mediterranean countries and have resulted in human casualties. The aim of this article is to investigate whether agroforestry, the practice of integrating woody vegetation and agricultural crops and/or livestock, could be a management tool to reduce wildfires in European Mediterranean countries. Fire events from 2008 to 2017 and data of land cover and land use were spatially correlated. Results indicated that agroforestry areas had fewer wildfire incidents than forests, shrublands or grasslands, providing evidence of the potential of agroforestry to reduce fire risk and protect ecosystems.

Introduction

The Mediterranean landscape is composed of a mosaic of different vegetation types which has been created not only by the evolution of plant species and influence of human activity, but also by climatic conditions and geomorphology (Quezel et al. 1977). The climate of the Mediterranean region is characterized by a complex interaction of large scale atmospheric patterns, the Mediterranean Sea and orographic factors (Ulbrich et al. 2012). This typically

results in a climate characterized by winter rains and summer droughts with large soil water deficits in summer. It is a temperate rainy, humid meso-thermal climate with dry subtropical warm to hot summers. The average temperature of the hottest month can be 22°C (Bolle 2003). The classification of climate, in Southern Europe, generally ranges from warm (Csa) to temperate (Csb) Mediterranean climate (Köppen 1918) and is characterized by hot dry summers and cool wet winters.

Dense stands of oak and coniferous forests prospered in the area as early as the Holocene era (Jahns 2005). Today, the characteristics of the natural vegetation of the Mediterranean region are governed by the Mediterranean climate but are also influenced by altitude, given the steep gradients that can extend almost immediately from the sea up to the high mountains.

Throughout human history, wildfires have played a major role in modifying land cover in the Mediterranean basin (Quezel et al. 1977; Thirgood 1981). Wildfires have been a natural part of the vegetation dynamics of the Mediterranean for much longer than there have been humans. It is nowadays widely accepted that the Mediterranean ecosystems includes many fire-adapted or fire dependent species, which can be easily reproduced by sprouting or seeding. Among the greater plant beneficiaries are woody shrubs and pine trees (Grove and Rackham 2001).

The existence of different forms of human activities, such as livestock production over many centuries, has resulted in the disappearance of most climax forest types from the Mediterranean region (Quezel 1978). The remaining natural forests, often managed by humans to some degree, have different stages of regressive succession of the original forest. In the typical Mediterranean zone, forests are composed of broad-leaved species, particularly oaks, both evergreen and deciduous. Another form of arboreal vegetation which is typical of the Iberian Peninsula and some Mediterranean islands is the ‘dehesa’, a type of pasture with scattered trees of evergreen and deciduous oaks, sometimes mixed with stone pine. Tree species vary based on the vegetation zone, elevation and geographical coordinates, as well as on the introduction of non-indigenous species in forest areas over time, most notably in the last century (Scarascia-Mugnozza et al. 2000).

According to the Global Forest Resources Assessment (FAO 2016), the global forest area declined by 129 million hectares (3.1%) in the period 1990–2015 to just under 4 billion hectares in 2015. In Europe this trend is not clear and depends on local circumstances. While in Northern Europe land intensification is an important driver for land use changes, the Southern European countries suffer from land abandonment (Plieninger et al. 2016). In the period between 2008 and 2017, the majority of European fire incidents (93%) occurred in Mediterranean countries. Each year, approximately 300,000 to 450,000 ha of forest area are burnt in Portugal, Italy, Spain, Greece, France, and Cyprus (San-Miguel-Ayanz and Camia 2010; San-Miguel-Ayanz et al. 2016) and these numbers are expected to increase in future decades due to climate change (Seidl et al. 2014). In addition, not only climate change can be affected by the increase in the number of fires (Lozano et al. 2017), but also the effects of climate change can increase the fire risk (number of days with fire risk, length of fire risk season etc.) for the EU Mediterranean countries (Moriondo et al. 2006).

There are many complex causes of wildfires in the Mediterranean. Biophysically, forest fires depend on the “fuel, oxygen, and heat” triangle to ignite and spread; thus, whatever the

preventive forest management actions are, they need to relate to the ‘‘fuel’’, ‘‘spread’’ or ‘‘cause of ignition’’. Unmanaged forests typically contain high fuel loads increasing the risk of large and rapidly spreading wildfires accompanied by large CO_2 emissions. Planning and implementing thinning and other management operations, which reduce the flammable load and the flammability of biomass, deprives the ‘‘fuel’’ part of the triangle. According to Salis et al. (2016), there is significant variation in wildfire exposure among and within areas that have implemented fuel management strategies and treatment intensities. This could also enhance the incorporation of organic matter in litter and deadwood pools and promote less flammable communities (Santana et al. 2018). Ganteaume et al. (2011) reported that increases in litter depth resulted in higher mean flame temperature and increased maximum flame height and flame propagation. The disruption of the vegetation continuum, the enhancement of organic matter turnover and its incorporation into the soil are important factors for forest fire reduction.

However, in recent decades, large-scale rural abandonment and moving of people to big cities has become a phenomenon characterizing many Mediterranean countries. This has resulted in the increase of flammable biomass (fuel) in forests that can then be easily ignited by anthropic activities and sometimes by natural events such as thunderstorms. Yet, forests provide many benefits to society including support for European bioeconomy (Verkerk et al. 2018), multiple environmental benefits, high quality products, and recreational benefits for human well-being. Agroforestry, as the deliberate integration of woody vegetation (trees and/or shrubs) and any combination of livestock, pasture or agricultural crops (MosqueraLosada et al. 2018), may provide one option for ensuring that such environmental services can be maintained, whilst managing the accumulation of fuel in Mediterranean forests to reduce wildfires.

The aim of this paper is to compare the occurrence of wildfires in agroforestry, forestry, shrubland and grassland land uses within the European Mediterranean region and to examine the evidence for the hypothesis that agroforestry is a more fire resilient landscape than forestry, shrubland and grassland.

Material and Methods

The study, whilst pertinent to the whole Mediterranean region, focused on the following countries: Cyprus, France, Greece, Italy, Portugal and Spain. A geographic information system (GIS) was used to investigate and analyze the spatial relationship between fire incidences and different land uses (agroforestry, forests, shrublands and grasslands).

The fire data used in this study was produced by the European Forest Fire Information System (EFFIS 2018; San-Miguel-Ayanz et al. 2018). The data present the burnt areas across the Mediterranean countries and include fires that are larger than 30 ha. Based on the previous dataset, the highest proportion of large fires occurred in Portugal (36%) followed by Italy (30.6%), Spain (22.5%), Greece (6.8%), France (3.5%) and Cyprus (0.6%). The datasets (shapefile) covered a period between 2008 and 2017 (10 years) and included information about the date of ignition and burnt area.

The Land Use/Cover Area frame Survey (LUCAS) is a harmonized in situ (direct observations) land cover and a land use data collection exercise that extends over the whole of the EU’s territory (LUCAS 2015). Land cover refers to the bio-physical coverage of land (for example,

natural areas, forests, buildings and roads or lakes) and has 8 categories, 29 classes and 76 subclasses. Land use refers to the socio-economic use that is made of land (for example, agriculture, commerce, residential use or recreation) and has 4 main categories, 16 classes and 31 subclasses; at any one place, there may be multiple and alternative land uses.

Another useful variable included in the LUCAS database is land management which contains information for grazing. By identifying certain combinations of primary land cover and land management (grazing), it is possible to identify grazed areas. We used a similar method as den Herder et al. (2017) to identify livestock agroforestry. However, for our assessment we included the LUCAS classes as shown in Table 1 and we did not include the LUCAS class of permanent crops (B71–B84), as areas with permanent crops are less susceptible to wildfires compared to areas with semi-natural vegetation. Agroforestry livestock systems were identified by selecting areas with woody vegetation which showed clear signs of grazing. First, we selected the primary land cover classes (LC1), ‘‘woodland’’ (C10 toC33), ‘‘shrublands with sparse tree cover’’ (D10), ‘‘shrublands without tree cover’’ (D20), ‘‘grasslands with sparse tree/shrub cover’’ (E10), ‘‘grasslands without tree/shrub cover’’ (E20) and ‘‘spontaneously re-vegetated surface’’ (E30) (Table 1). From this set of points, only those showing signs of grazing were recorded as livestock agroforestry. According to den Herder et al. (2017), these estimates were quite rough, but for those countries with a large agroforestry cover (Portugal, Spain and Greece), the LUCAS assessment corresponded quite well with earlier assessments and literature reviews. After processing, the LUCAS 2015 point dataset was spatially combined with the polygon data from EFFIS 2018, for the period 2008–2017 (San-Miguel-Ayanz et al. 2018).

Table 1: The designation of forest, shrubland, grasslandand agroforestry areas within the LUCAS 2015 (2 km x 2 km), and the CORINE (100 m x 100 m) dataset

	Forest	Shrubland	Grassland	Agroforestry	Resolution
LUCAS 2015	C10 (Broadleaves woodlands) C20 (Coniferous woodlands) C30 (Mixed woodlands)	D10 (Shrublands with sparse tree cover) D20 (Shrublands without tree cover)	E10 (Grasslands with sparse tree/shrub cover) E20 (Grasslands without tree/shrub cover) E30 (Spontaneously re-vegetated surface)	Den Herder et al. (2017)	Point dataset 2 km x2 km
CORINE 2012	311 (Broad-leaved forest) 312 (Coniferous forest) 313 (Mixed forest)	322 (Moors and heathland) 323 (Sclerophyllous vegetation) 324 (Transitional woodland-shrub)	Grasslands 321 (Natural grasslands)	244 (Agroforestry areas)	Polygon dataset (Minimum mapping unit of 25 ha for areal phenomena and a minimum width of 100 m for linear phenomena)

An alternative method of calculating the area of agroforestry, forest, shrubland and grassland is to use the CORINE land cover dataset (Table 1). The land cover project is part of the CORINE programme and is intended to provide consistent localized geographical information on the land cover of the Member States of the European Community. The same process was followed (after the separation of land cover) for CORINE 2012 data, which were

also combined with the EFFIS 2018 data (San-Miguel-Ayanz et al. 2018). The two combinations of data (LUCAS–EFFIS and CORINE–EFFIS) allowed us to intersect, identify and compare the total number of fires (NF) occurring in each Mediterranean country within agroforestry, forests, shrublands, and grasslands land cover/uses.

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Results

The burnt areas and the number of forest fire incidents from EFFIS 2018 (San-Miguel-Ayanz et al. 2018) for each of the selected Mediterranean countries of the EU for the time-period between 2008 and 2017 are presented in Table 2. Although Portugal is the second smallest of the investigated countries (Nunes et al. 2005), in this period, it was affected by a relatively high number of forest fires in comparison with other Mediterranean countries of the EU.

Table 2. Burnt area, number of fires (proportion of the burnt area and number of fires), area of countries and proportion of burnt area per county for six Mediterranean countries, between 2008 and 2017.

Countries	Burnt area (ha)	Number of fires	Area of countries (ha)	Burnt area (%) per country
Cyprus	13,258 (0.5%)	39 (0.6%)	925,100	1.4
France	61,558 (2.2%)	247 (3.5%)	55,169,500	0.1
Greece	258,440 (9.3%)	476 (6.8%)	13,194,000	2.0
Italy	447,795 (16.2%)	2,152 (30.6%)	30,133,800	1.5
Portugal	1,317,266 **(47.5%)**	2,538 **(36.0%)**	9,156,800	14.4
Spain	674,551 (24.3%)	1,587 (22.5%)	49,846,800	1.4
Total	**2,772,868 (100%)**	**7,039 (100%)**		

Bold indicates the highest percentage value

Values in brackets are the proportion of the total. Fires under 30 ha are not included.

Fires and LUCAS land use categories

Data derived from the LUCAS database 2015 were analyzed for land use and land cover for each Mediterranean country. Table 3 presents the number of points identified for the different land uses and their relative occurrence in each land use type. Because of the small size, Cyprus had relatively lower number of points. France, the largest of the countries studied, had the largest number of points for forest and grassland land uses. Spain had the largest number of agroforestry and shrubland points (Table 3). In Portugal, which shows the highest fire incidents of all the Mediterranean countries (Table 2), agroforestry counted only for 9.4% of the total land use of the country (Table 3). The area of agroforestry was similar to that of shrublands (11.7%) and grasslands (11.8%), but less that the area of forest (67.1%).

Table 3. Points from the LUCAS dataset per land use for each Mediterranean country

Country	Number of points				
	Agroforestry	Forests	Shrubland	Grassland	Total
Cyprus	74 (7.4%)	359 (**36**%)	348 (34.9%)	217 (21.7%)	998
France	1,100 (4.6%)	10,828 (**45.3**%)	1,251 (5.2%)	10,722 (**44.9%**)	23,901
Greece	957 (17%)	1,686 (29.9%)	1,971 (**35%**)	1,020 (18.1%)	5,634
Italy	979 (8.8%)	5,612 (**50.2%**)	1,307 (11.7%)	3,272 (29.3%)	11,170
Portugal	963 (9.4%)	6,882 (**67.1%**)	1,201 (11.7%)	1,213 (11.8%)	10,259
Spain	3,961 (**23.8%**)	2,115 (12.7%)	4,995 (**30%**)	5,566 (33.5%)	16,637
Total	8,034 (11.7%)	27,482 (40.1%)	11,073 (16.1%)	22,010 (32.1%)	68,599

The relative occurrence (%) of these for each of the six countries is shown in brackets (in bold the highest percentage per country).

Table 4 describes the proportion of fire points that were categorized according to the four selected land uses. The lowest proportion of fires (ranging from 0 to 12.5%) occurred in agroforestry points in all countries, except Greece where the proportion of fires was lowest in forest areas. The highest numbers of fires occurred in shrubland (40.6%) and forest (37.1%), for the same time span. The average percentage of fire points that occurred in grassland areas was 16.6%.

Table 4. Proportion of each land use in each Mediterranean country with incidents of fire, based on LUCAS and EFFIS 2018 (in bold the lowest percentage per country)

Countries	Number of points included in the fire polygons				
	Agroforestry %	Forest %	Shrubland %	Grassland %	Total (#)
Cyprus	**3.6**	21.4	53.6	21.4	28
France	**0.0**	26.7	43.3	30.0	30
Greece	12.5	**10.2**	65.6	11.7	128
Italy	**11.7**	25.7	22.9	39.7	179
Portugal	**2.6**	46.8	39.5	11.1	648
Spain	**6.4**	36.9	41.2	15.5	328
Mean of all countries	5.7	37.1	40.6	16.6	1341

Fire and CORINE land cover categories

The focus of our research was not on the burnt area in hectares, but the occurrence of fires (as incidents) inside each different ecosystem type (polygons). Hence, we calculated for each country the number of polygons in the selected four land covers (Table 5).

According to the CORINE 2012 database, the lowest proportion of fires occurred within agroforestry polygons in three countries France, Italy and Spain (Table 6). In Greece and Cyprus (Table 6), the proportion of fires was lowest in the forest areas and in Portugal the proportion was lowest in grasslands. The average fire incidents for all the countries, showed the lowest incidents of fire for grasslands (11.2%) and agroforestry (20.2%). In contrast, the highest average was recorded in shrublands (36.7%) and forests (31.9%).

Table 5. Numbers of polygons from the CORINE dataset per land use for each Mediterranean country.

Countries	Number of points included in the fire polygons				
	Agroforestry	Forests	Shrubland	Grassland	Total
Cyprus	230 (0.3%)	110 (0.1%)	505 (0.5%)	80 (0.2%)	925
France	24,335 (**29.1%**)	68,688 (**44.9**%)	18,493 (18.2%)	5,205 (13.3%)	116,721
Greece	10,928 (13.1%)	6,559 (4.3%)	10,853 (10.7%)	4,493 (11.5%)	32,833
Italy	16,808 (20.1%)	20,317 (13.3%)	15,042 (14.8%)	6,041 (15.4%)	58,208
Portugal	9,802 (11.7%)	10,588 (6.9%)	10,358 (10.2%)	922 (2.3%)	31,670
Spain	21,484 (25.7%)	46,574 (30.5%)	46.342 (**45.6%**)	22,495**(57.3%)**	136,895
Total of all countries (% land use per total)	83,587 (22.2%)	152,836 (40.5%)	101,073 (26.9%)	39,236 (10.4%)	377,252 (100%)

The relative occurrence (%) for each of the six countries is shown in brackets (in bold the highest percentage per land use category).

Table 6. Proportion of each land use for each Mediterranean country with incidents of fire, based on CORINE 2012 and EFFIS 2018 (in bold the lowest percentage per country)

Countries	Proportion of CORINE polygons included in the fire polygons				
	Agroforestry %	Forests %	Shrublands %	Grassland %	Total (#)
Cyprus	25.4	**7.9**	55.6	11.1	63
France	**7.6**	38.7	37.1	16.5	630
Greece	34.7	**12.3**	36.9	16.2	1,884
Italy	**18.5**	30.7	31.5	19.3	3,787
Portugal	35.7	34.3	36.9	**4.5**	8,211
Spain	**8.0**	24.0	27.1	9.1	5,602
Mean of all countries	20.2	31.9	36.7	11.2	20,177

The relationship between the number of fire incidents and the land use, varied within country. For example, the occurrence of forest fire in Portugal was almost the same on every land cover except for grasslands which was very low (Table 6). The explanation may be that grasslands in Portugal cover a very small area of land compared with other Mediterranean countries (Table 2). Another cause can be related to the economic relevance of agricultural production in Portugal, which contrasts to the lack of management and fuel load accumulation in several forest areas, which are largely located in the northern part of the country. Despite the different databases used for the analysis, the results both from LUCAS (Tables 3, 4) and CORINE (Tables 5, 6), showed that agroforestry areas frequently had fewer and often the fewest fire incidents in the investigated countries.

Finally, based on the results corrected for the extent of land use, the proportion of fires that occur in shrublands is greater ($P<0.001$) than those that occur in forests, grassland, and agroforestry areas. Across the six countries, although shrubland occupied 16% of the land area by the four land uses (Table 3), there were associated with 40% of the fires (Table 4). Although the response was not statistically different from that for forest and grassland areas, agroforestry, which occupied 12% of the area was only associated with 6% of the fires.

Discussion and conclusion

Wildfires can occur where there is a combination of flammable fuel, heat, and a source of ignition. The levels of flammable fuel are likely to be greatest when there is a combination of high tree growth rates (perhaps during the winter and spring) followed by dry hot summers. Such conditions occur in Northern Portugal and the North-Western part of Spain (Galicia) which can support high growth rates (Rigueiro Rodríguez et al. 2009; Scarascia-Mugnozza et al. 2000).

In this sense, in those Mediterranean countries showing the highest tree growth rates in Europe, such as the west part of Spain and north part of Portugal the accumulation of vegetation (fuel) is faster than in Eastern and Southern areas of Mediterranean countries. Once the vegetation is accumulated, the ''fuel-oxygen-heat'' triangle becomes significant and large fires are more likely to occur. Both the high vegetation growth and the occurrence of the triangle ratio help explain why lands in Northern Portugal and in the North-Western part of Spain (Galicia) are relatively fire prone. These Western Mediterranean regions have extensive areas of land allocated to high stand forest, due to the high and rapid economic returns from plantations with no associated costs (no need to prune or thin), usually fast-growing tree species such as *Eucalyptus* spp. that are over 40% of the burnt forest area. Because of the high biomass accumulation, the lower humidity and the higher temperatures reached under *Eucalyptus* and *Pinus* stands compared with broadleaves such as *Quercus robur* or *Q. pyrenaica* (Arellano et al. 2017), the speed and spread of forest fires are greater and make the extinguishing of fires very difficult. *Eucalyptus* spp. is a profitable species thanks to its high growth rate but has negative impacts when planted in areas with long summer droughts as it accumulates biomass too rapidly. It is highly flammable due to its high dry matter content and oil resin composition (Wolf and Ditomaso 2016), and when ignited, the leaves and bark of *Eucalyptus* are lifted into the air, sending fragments of burning dry matter sometimes several kilometers from the fire front, to igniting new fires (Richardson and Rejmánek 2011).

Land abandonment is also another important reason for possible fire events. In many parts of the Mediterranean region, especially in marginal areas, the aging of the rural population and the abandonment of traditional activities linked to forestry and agriculture, have created extensive unmanaged lands. In addition, most Mediterranean regions with slow vegetation growth rates, shrublands and forests are usually linked to land abandonment and slow growing forests (with rotations of over 100 years) and are managed mostly for protection. Compared with Northern European countries, which experience less than three months of drought, the southern European countries are subjected to summer droughts that can regularly last from three to six months (EEA 2016). The lack of water due to low rainfall, high temperatures, high vapor pressure deficits and high evaporation rates, increase vegetation fire risks (Baeza et al. 2011) in those areas. The dry biomass accumulation represents a continuous risk, a major component of the ''fire triangle''.

Den Herder et al. (2017) found that in the six countries studied in this investigation, agroforestry was most common in south, central and north-east Portugal, south-west, central and parts of north Spain, south of France, Sardinia, south and central Italy, central and north-east Greece (Fig. 1).

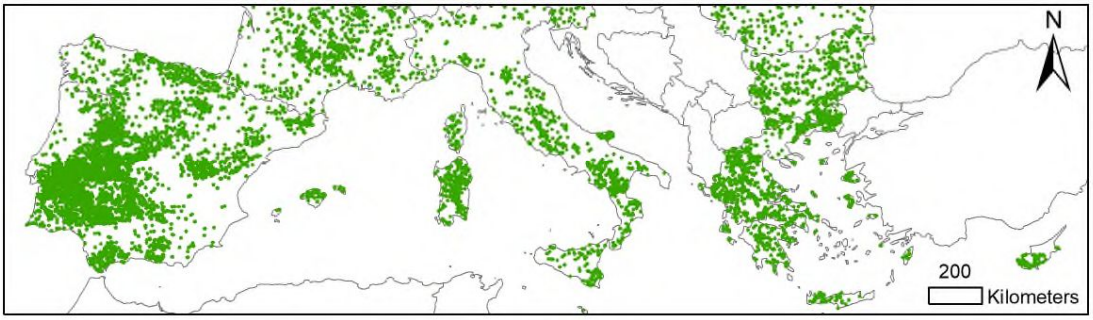

Fig 1. Distribution of livestock agroforestry in the European part of the Mediterranean based on LUCAS data (figure reproduced from den Herder et al. 2017)

In Spain, Portugal, Italy, and Greece silvopastoral systems were most commonly associated with broadleaved woodland (C10) (den Herder et al. 2017). In Cyprus and France, silvopastoral systems were most often associated with grasslands with sparse tree cover (E10). Silvopastoral systems associated with shrublands with sparse tree cover (E10) were also common in all six countries. Silvopastoral systems associated with pine dominated coniferous woodlands (C22) were found to some extent in all countries and were quite common in Spain and Cyprus. France shows significant fire problems mostly in the Southern areas of the country and on the island of Corsica, while Central and Northern parts of France are generally unaffected by wildfires. This has influenced the results for France for both land cover types and their relations with fire events.

Paris et al. (2019) reported that the greatest diversity and cover of silvopastoral systems in Italy is found in Sardinia. These dehesa-like systems are mainly dominated by cork oak and are grazed by sheep, goats and beef cattle. In Calabria, Campania, Apulia and Sicily historical rural landscapes with residual patches of ancient silvopastoral systems are still present (Paris et al. 2019). Greece has a large diversity of silvopastoral systems (Papanastasis et al. 2009). Examples of silvopastoral systems associated with broadleaved woodland include valonia oak, Kermes oak and Macedonian oak forests (Papanastasis et al. 2009). In Spain, there is scientific evidence on the low vulnerability to wildfires in agroforestry landscapes of integrated management (‘‘dehesas’’) shown over 50 years in comparison with other land uses (Ortega et al. 2012). The same authors also reported that one of the most vulnerable landscapes for fire are mosaics of land use where forests, crop land and pasture are combined but where there is no integrated management and where there are different owners. Agroforestry can help reduce the fire risk by removing part of the under story vegetation whilst also providing revenue from the sale of the biomass as food or fuel, increasing biodiversity, reducing soil erosion and protecting water (Rigueiro-Rodríguez et al. 2009). This study clearly supports the potential of agroforestry as a tool for wild-fire risk reduction as fire frequency is lower in the agroforestry areas. The reason for this is in the way that agroforestry breaks the continuum of the shrubland trees, increasing the spacing of trees and reducing forest understory biomass relative to forest (Rigueiro-Rodríguez 2008, 2009).

The south of Portugal and central-west part of Spain are mostly agroforestry land (dehesa in Spain and montado in Portugal) where a lower occurrence of fire has been identified due to

the lower growth rate of the vegetation, lower tree density and the use of grazing livestock by farmers. Such silvopastoralism is more effective and cheaper for reducing understory fuel than mechanical clearance. The major advantage of silvopastoralism is that livestock reduces the flammable biomass in the understory (especially grass and woody vegetation of low height) whilst also enhancing organic matter decomposition and nutrient mobilization through soil trampling, and diversifying and enhancing farmer income through livestock products which are generally of high quality (Rigueiro Rodríguez et al. 2009). In fact, relative to mechanical clearance of under storey, agroforestry can contribute to lower consumption of machinery fuel and greenhouse gas emissions. Given these benefits, land use policies should be developed to encourage agroforestry.

Species composition is another important factor in the development of fires, as this affects flammability. Species flammability is the result of a number of factors. Ecosystem flammability is an emergent property of plant communities (Lavorel and Garnier 2002; Schwilk 2003) that involves interacting biotic and abiotic processes. Flammability in all species depends on the leaf water availability and volatile terpene content and emission (Alessio et al. 2008). The predicted increases in future temperature and decreases in water availability due to climate change may result in an increased flammability of shrub and forest species, especially of those storing volatile compounds. Taking into account the effect of climate change on Mediterranean ecosystems, agroforestry provides a sustainable option for land management of fire risk.

The application of both prevention and suppression measures is a key part of reducing fire risk. Short-term prevention measures include silvopastoralism, thinning, clearing, and pruning, and, where appropriate, the use of prescribed burning. Selection, distribution and management of low-density trees in high risk areas are also a key tool for reducing fire risks in those areas. Such measures require long-term planning to be effective.

Horses, pigs and goats have a preference for feeding on woody shrubs and young trees and will help convert land to a more herbaceous cover, where animals with a preference for less woody vegetation, such as cows and sheep, can graze. Relevant factors for controlling the biomass are (1) the stocking rate, for example one goat for 1–2 ha or one-horse for 2–4 ha in north-western Spain and (2) continuous or rotational grazing patterns (Rigueiro-Rodríguez et al. 1999). There are successful agreements between herders and local authorities that have introduced livestock in firebreaks to keep them clear of biomass, thereby proving their function (Dopazo and Suárez 2004; Ruiz-Mirazo et al. 2011). This practice is also relevant at the interface of urban and densely vegetated areas.

Moreno et al. (2014) have referred to economic studies showing that silvopastoral systems are generally more profitable than single timber production systems when fire risk is included in the analysis, and that forest grazing is the most cost-effective fire prevention system. To conclude, this initial analysis of European data has provided evidence to show that agroforestry is a land management option that can successfully reduce fires and, subsequently, help protect the environment and improve human well-being.

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